PB 198 080

EVALUATION OF THE PICKER CAPACITOR DISCHARGE MOBILE X-RAY MACHINE

G. F. Grove, Jr., Et al

U. S. Department of Health, Education and Welfare
Rockville, Maryland

February 1971

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BRH DEP 71-3

EVALUATION of the PICKER CAPACITOR DISCHARGE MOBILE X-RAY MACHINE

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X-ray Exposure Control Laboratory

and

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Product Testing and Evaluation Branch

Division of Electronic Products

February 1971

U.S. DEPARTMENT OF HEALTH, EDUCATION, AND WELFARE
Public Health Service
Bureau of Radiological Health
Rockville, Maryland 20852

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FOREWORD

The Bureau of Radiological Health continues to carry out a national program designed to reduce the exposure of man to hazardous ionizing and nonionizing radiation.

Within the Bureau, the Division of Electronic Products (1) develops and administers performance standards for radiation emissions from electronic products, (2) studies and evaluates emissions of and conditions of exposure to electronic product radiation and intense magnetic fields, (3) conducts or supports research, training, development, and inspections to control and minimize such hazards, and (4) tests and evaluates the effectiveness of procedures and techniques for minimizing such exposures.

The Bureau publishes its findings in Radiological Health Data and Reports (a monthly publication), Public Health Service numbered reports, appropriate scientific journals, and technical report series for the Bureau's divisions, offices, and laboratories.

The technical reports of the Division of Electronic Products (DEP) allow comprehensive and rapid publishing of the results of intramural and contractor projects. The reports are distributed to State and local radiological health program personnel, Bureau technical staff, Bureau advisory committee members, university radiation safety officers, libraries and information services, industry, hospitals, laboratories, schools, the press, and other interested individuals. These reports are also included in the collections of the Library of Congress and the National Technical Information Service.

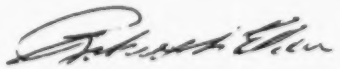
I encourage the readers of these reports to inform the Bureau of any omissions or errors. Your additional comments or requests for further information are also solicited.

John C. Villforth
Director
Bureau of Radiological Health

PREFACE

The Radiation Control for Health and Safety Act of 1968 authorizes the Secretary of Health, Education, and Welfare to establish an electronic product radiation control program which includes the development and administration of performance standards to control the emission of electronic product radiation. Performance standards are currently being developed for diagnostic x-ray equipment used by practitioners of the healing arts. To develop appropriate standards for new x-ray apparatus such as capacitor discharge equipment, typical operational data must first be obtained.

This report reflects the efforts of the Division of Electronic Products to keep informed of new and unusual types of commercial x-ray equipment and to gather information related to operating characteristics and radiation exposure in the use of such equipment. It presents the results of measurements made to determine the physical and operating characteristics of the Picker model DGC-1010 capacitor discharge mobile x-ray machine. Although the results presented herein are considered accurate, they are not intended to certify that the Picker machine complies with forthcoming performance standards, nor should the test methods described be considered the official methods for determining compliance.



Robert L. Elder, Sc. D.
Director
Division of Electronic Products

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ABSTRACT

Tests were performed on a Picker model DGC-1010 capacitor discharge mobile x-ray machine to determine accuracy of voltage and current-time indications, line voltage effects and current drain, exposure reproducibility, focal spot size and location, correspondence between the collimator and light localizer, inherent filtration, half-value layer, radiation output, and tube housing and collimator leakage. Spurious radiation was found to originate in the tube under certain conditions. These conditions were investigated, and the observed radiation levels are reported. To determine beam quality differences between capacitor discharge and conventional equipment, comparisons were made of half-value layer and step-wedge and phantom radiographs.

EVALUATION of the PICKER CAPACITOR DISCHARGE MOBILE X-RAY MACHINE

1. INTRODUCTION

Although the capacitor discharge principle of x-ray generation is not new, it has not been in general use in the United States until recently. Five manufacturers are currently producing mobile capacitor discharge machines for sale in the United States, and their use is spreading. This report is the first of a series of reports on the various makes available.

The capacitor discharge principle is employed in a mobile radiographic unit so that the machine can be operated from a normal low-current wall outlet, eliminating the need for special wiring at the various locations where use is intended. Such operation is possible because a charge sufficient to produce a reasonable x-ray exposure in a short time is stored in capacitors prior to exposure. The charge is accumulated over a much longer time period, eliminating the sudden surge during exposure required by conventional equipment.

Although the results reported here are considered accurate, the test methods described should not be considered to be the official methods for determining legal compliance with forthcoming performance standards authorized by the Radiation Control for Health and Safety Act of 1968.

2. DESCRIPTION OF MACHINE

The Picker capacitor discharge mobile x-ray machine is shown in figure 1. The machine tested for this report was a model DGC-1010, serial number 44-213-8. The wheels are fitted with brakes which are released whenever the brake release bar is held in toward the main handle. The unit can be moved by one person. The tube head can be oriented in any direction, and the collimator can be rotated about the axis of the beam. Friction locks are available for all motions. The face plate of the collimator is 22 cm from the focal spot, but guard rails on the collimator extend to 30 cm to indicate the minimum recommended source-skin distance. A shorter source-skin distance can be realized in the case of extremities by placing them between the rails which are 15 cm apart. Boxes are attached outside the cabinet for carrying cassettes and storing the power cord while the machine is being moved. The cassette box is partially lined with steel. A handle in the rear of the control unit allows the capacitors to be shorted mechanically.

The control panel and remote hand switch are shown in figure 2. The LV control compensates for different line voltages, and the LV meter indicates the correct setting. The kV control determines the initial voltage that will be placed on the capacitors, and the meter indicates the capacitor voltage. The mAs control determines the milliampere-seconds of an exposure, with the "full" position allowing the capacitors to discharge completely. The remote hand switch has two buttons and a light. The light indicates that a charge or exposure operation is occurring. The white button starts the charge operation, which can be stopped before completion by the black button or the "charge stop" button on the control panel. After charging, the black button prepares the machine for exposure, and the white button makes the exposure.

A block diagram of the circuit is shown in figure 3. Solid lines indicate specific circuit connections, while dotted lines indicate information flow. When the charge button is pressed, the control circuits energize the high-voltage supply which charges the capacitors. The anode and the cathode each have a capacitor bank to ground, and are charged respectively to plus and minus one-half the total

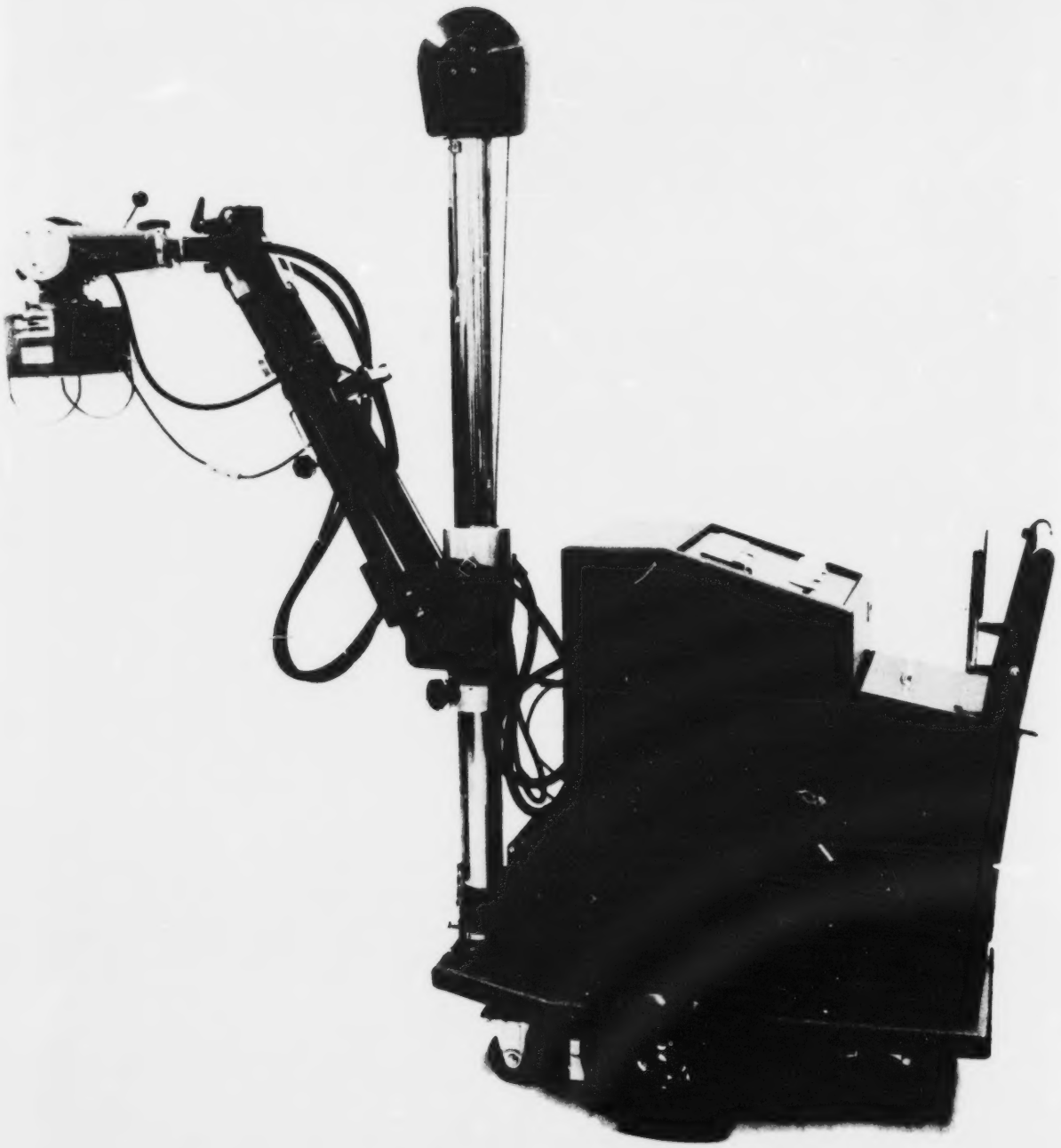

Figure 1. Picker capacitor discharge mobile x-ray machine.

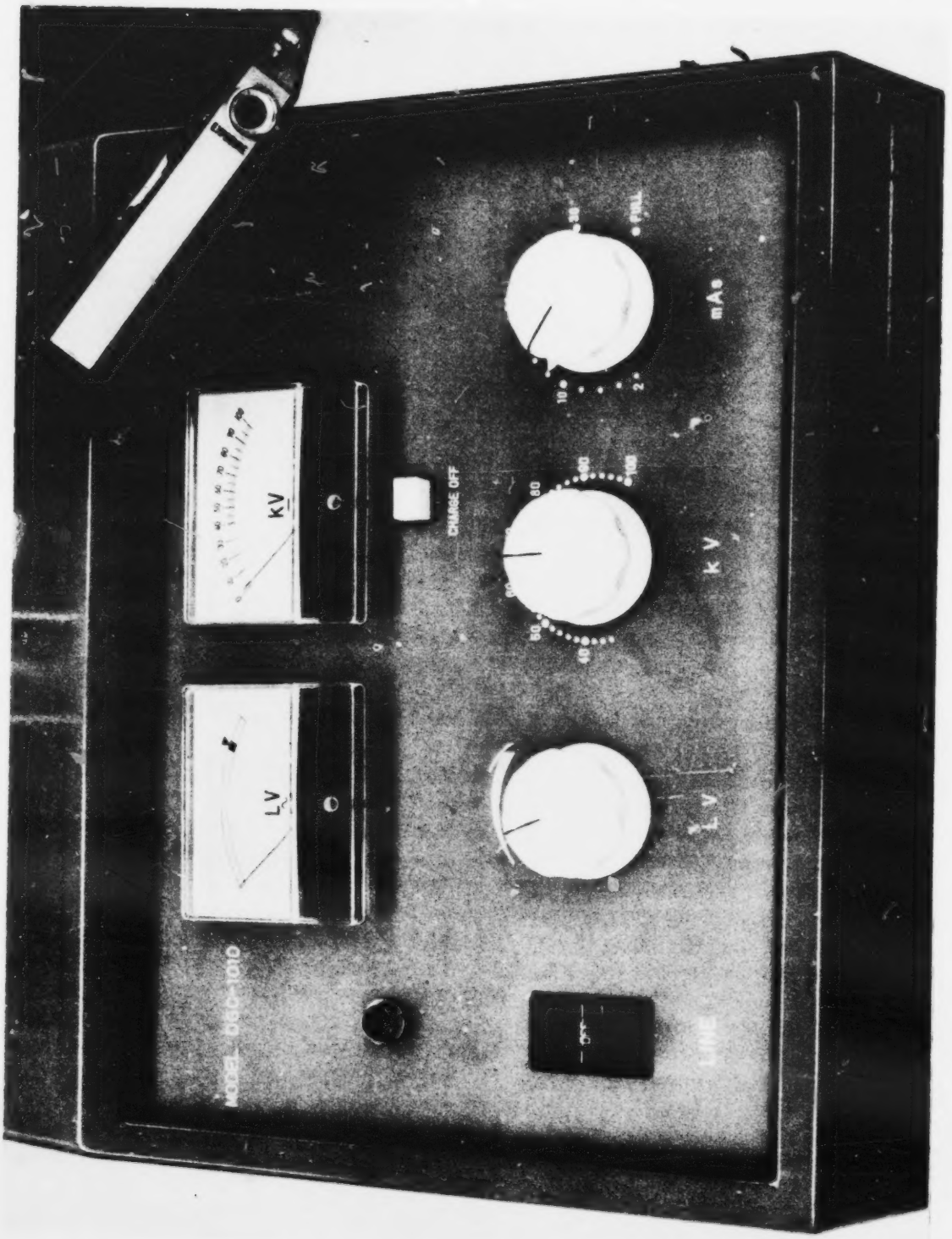

Figure 2. Control panel and remote hand switch of Picker machine.

NOT REPRODUCIBLE

voltage. When the preset voltage is reached, the kV sensing circuit causes the high-voltage supply to be deenergized. The capacitor voltage appears across the tube at all times, but the tube is grid-controlled and normal tube conduction is suppressed by application of a negative bias on the grid. When an exposure is to be made, pressing the exposure preparation button causes the tube filament to heat to full temperature and initiates anode rotation. After 1-1/2 seconds, if the charge/discharge button is pressed, the grid bias is removed and current through the tube causes the production of x rays. The mAs sensing circuit stops the exposure by reapplying the grid bias after the selected amount of charge has passed through the tube. The capacitors, which have a nominal combined value of 1.0 μF, discharge about one kV for each mAs of exposure. If the mAs control is set to full, the capacitors are allowed to discharge to a low voltage through the tube.

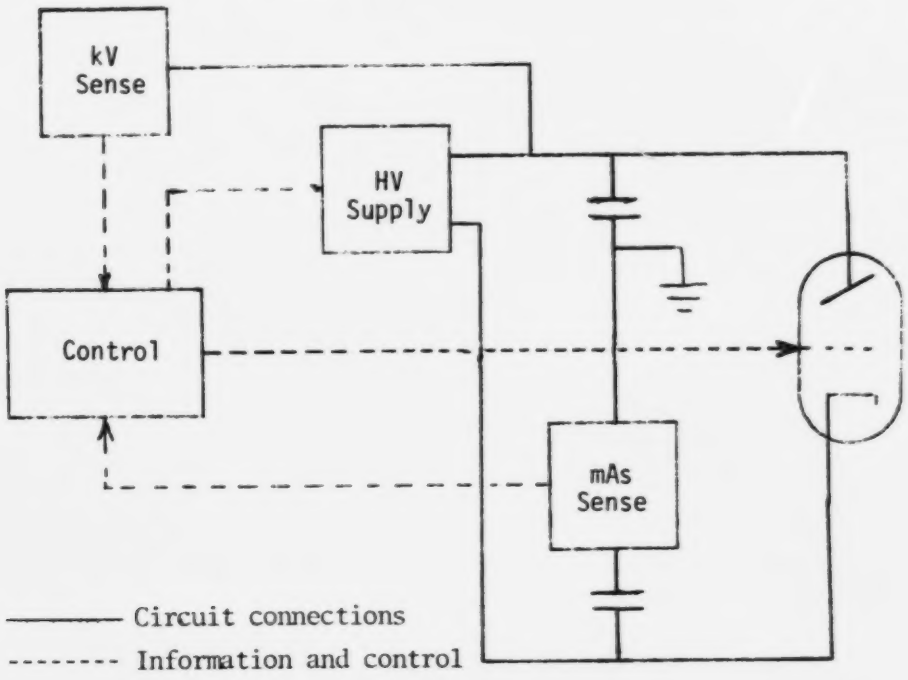

Figure 3. Block diagram of Picker machine circuit.

3. MEASUREMENTS AND TESTS

3.1 VOLTAGE MEASUREMENTS

The anode and cathode voltages were measured with a resistance voltage divider. The magnitude of the cathode voltage was less than that of the anode by one percent. The anode voltages were measured at various settings and multiplied by 1.99 to give the total tube voltage.

Figure 4 shows the relationship between the kV control, the meter indication, and the voltage measured with the voltage divider. The vertical position represents the measured voltage, and the horizontal position represents the reading of the panel meter. Each point plotted in figure 4 indicates a measurement taken at the setting of the kV control noted beside it. The maximum errors between the preset, indicated, and measured voltage occur at a setting of 100 kV which yields a voltage of 105 kV and an off-scale meter indication of about 102 kV. Below 80 kV, these errors are 1 kV or less. In this report, kV and mAs values given are those values indicated by the controls unless otherwise stated.

The capacitors which store the x-ray producing charge are part of Cockcroft-Walton voltage multiplying circuits composed of diodes and capacitor banks. Therefore, there is no unique value of capacitance. The effective capacitance is composed of the anode and cathode capacitors in series and varies between 0.9 and 1.1 μF, depending on the degree of discharge. The nominal value is 1.0 μF. During an exposure the capacitors are discharged and the tube voltage falls approximately 1 kV for each mAs of exposure.

The capacitors in the anode and cathode supplies, each of nominal 2.0 μF capacitance, are shunted with bleeder resistors of 250 megohms and 265 megohms, respectively. These cause the capacitor voltages to decay exponentially toward zero with a time constant of about 8 minutes. The charging time from full discharge is 4 seconds for 70 kV and 20 seconds for 100 kV.

After the capacitors have been charged for a short time, some of their charge is stored in the dielectric and is not immediately released when they are discharged. This residual charge reappears as a voltage on the capacitors a few minutes after discharge. The voltage from this source may be as high as 500 volts. The potential shock hazard from this residual charge is not mentioned in the instruction manual provided with the unit. The Division of Electronic Products has found

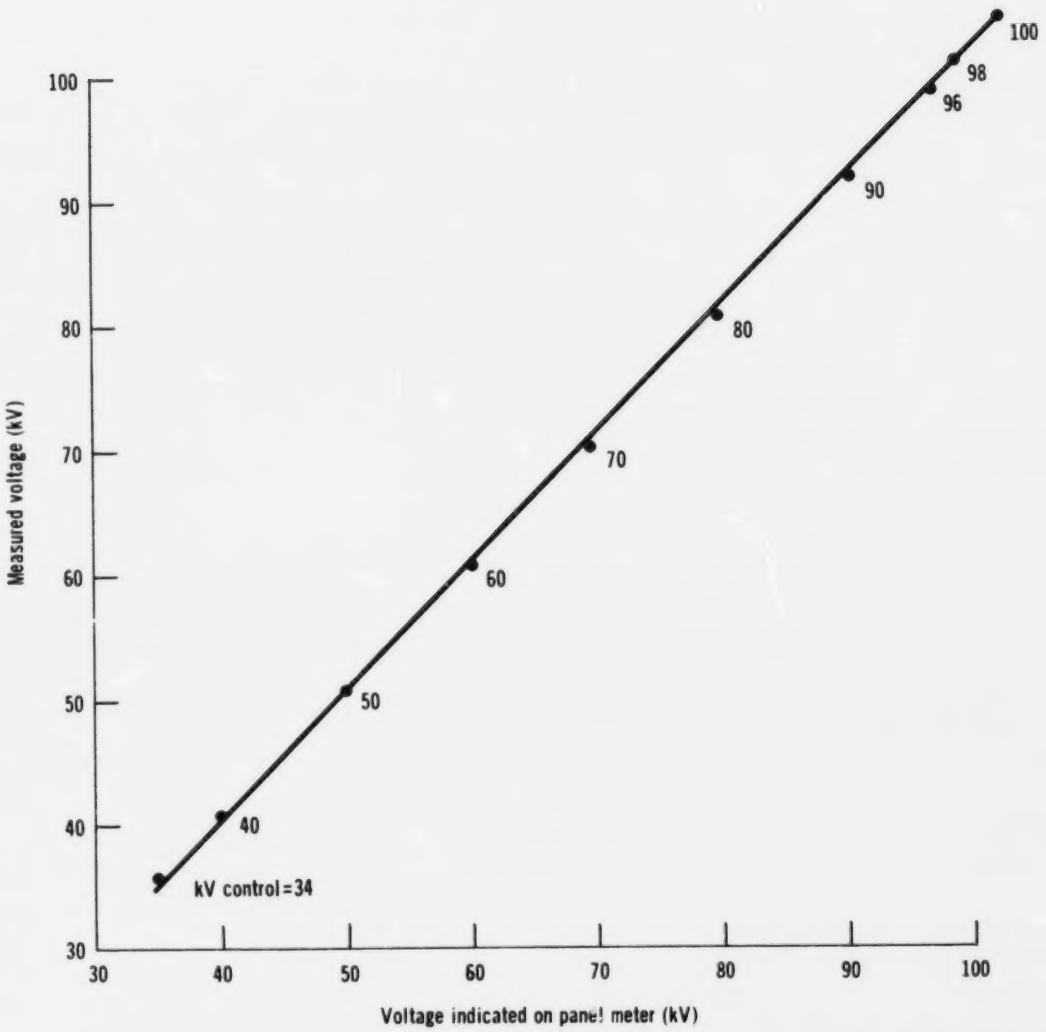

Figure 4. Relationship between kV control, meter indication, and voltage measured with voltage divider.

that this hazard can be minimized by taking the following steps before removing the high-voltage cables after the machine has been in use. (1) Discharge the capacitors through the tube with the collimator closed, using the full position on the mAs control or successive exposures without recharging. (2) Pull the mechanical discharge handle. (3) After a 5-minute delay to allow the capacitors to "relax", pull the handle again before removing the cables.

The kV meter is connected to the anode capacitor, and there is nothing to indicate voltage on the cathode side. This would be misleading and hazardous in the event of failure of the cathode-side mechanical shorting mechanism, but because of its extremely simple nature, such failure is very unlikely. To prevent the possibility of serious shock, the capacitors should be discharged by repeated exposures before the handle is operated.

The instruction manual warns users not to change the kV charging-level setting after charging and before making an exposure. The reason for this is that the tube current is higher below 65 kV than it is above. If the capacitors are charged to a voltage above 65 kV and the kV knob then set below 65 kV, the combination of high voltage and current may damage the tube.

3.2 mAs MEASUREMENTS

To facilitate estimation of the tube current, a 100-ohm resistor is provided in the ground-return lead from the high-voltage supply. This lead does not carry the actual x-ray tube current, nor does its current bear a simple relationship to the true tube current, although the two currents differ by less than 20 percent. Because this current is similar in amplitude and waveform to the tube current, it was used to calibrate a ballistic mAs meter by direct comparison with an integrating digital voltmeter. Both meters measured the return lead current simultaneously. The ballistic meter was then placed in the anode lead to measure actual mAs. Although the ballistic meter was intended for current waveforms produced by conventional machines, it was found to be accurate for this machine provided the exposure duration was less than a few tenths of a second. Exposures with a final voltage of greater than 20 kV were sufficiently short for an accurate reading without correction.

Table 1 gives the corrected mAs values as a function of mAs and kV settings.

Table 1. Measured vs indicated mAs.

Indicated mAs	Measured mAs			
	40 kV	60 kV	70 kV	90 kV
2	4.5	4.8	3.7	4.0
16	16.3	15.4	15.6	14.6
30	42.6	34.0	34.4	33.4

The technique chart furnished by the Picker Corporation does not indicate use of the full-discharge setting for any technique. We feel that a full-discharge exposure has little or no radiographic usefulness, because the additional radiation compared to a 30 mAs exposure all occurs at 30 kV or more below the starting voltage. This low-energy radiation would add to patient exposure without significantly increasing radiographic density.

3.3 LINE VOLTAGE AND CURRENT

To adjust for differences in line voltage, a line voltage control and meter are provided. The meter face has a shaded segment with a marker at its center to indicate correct adjustment (fig. 2). The range of the control allows correct adjustment for any line voltage between 91 and 138 volts. The shaded area indicates a variation of about plus and minus 3 percent from the correct voltage. The variation in operation for changes in line voltage was studied by adjusting the LV control to give a meter indication at the high and low ends of the shaded segment in this range. No change in the charging kV was found, except that at low line voltage the unit would not charge above 98 kV. The observed mAs values changed about 2 percent in the

same voltage range. The instantaneous tube current, however, changed rapidly with line voltage. Although this has no effect on total radiation output, the exposure time increases at low voltages, and the tube may be damaged by excessive current at high voltages. Therefore, the line voltage should always be set and maintained at the proper level. The shaded segment should be considered to be the maximum permissible variation.

The peak current drawn from the line is about 18 amperes at 125 volts. This occurs at the beginning of the charging period. The current falls to 15 amperes in 2 seconds, 10 amperes in 3 seconds, and continues to fall as the capacitors are charged. Standby current is less than 1 ampere.

3.4 EXPOSURE REPRODUCIBILITY

Exposure reproducibility was checked at 40, 60, 70, and 100 kv; 2, 16, and 30 mAs. Standard deviations were calculated from a sample of ten exposures for each combination of the above technique factors. In the worst case (100 kV, 16 mAs) the standard deviation of exposure was 2.6 percent of the average value. In all but three cases the standard deviation was 1.6 percent or less.

3.5 FOCAL SPOT SIZE AND LOCATION

The location of the focal spot was determined by inserting a lead diaphragm with two pinholes 1.4 cm apart into the beam. The distance between the two focal spot images on film is used to calculate the distance from the focal spot to the pinholes. The average of several determinations showed that the focal spot was 4.9 cm behind the tube housing face. The tape measure mounted on one end of the tube housing to indicate distance from the focal spot was accurate to within 0.2 cm.

The focal spot size was determined according to the method recommended by the ICRU.[1] An image of the focal spot was produced by placing a diaphragm with a 0.075-mm-diameter pinhole between the focal spot and the film. Several images were made at various distance ratios, and the effective focal spot size was found to be 2.4 by 2.6 mm.

3.6 BEAM COLLIMATION AND LIGHT LOCALIZER

The relationship between the x-ray beam and the light localizer was determined by marking the edge of the lighted area with lead pieces on a sheet of film. The film was then exposed with the lead markers in place. The edge of the light field is defined as the point where the intensity of the light is 1/4 of its level at the center, determined with a narrow-field light meter. The edge of the x-ray beam is the point where the exposure is 1/10 of its level at the center, as determined from the film density.

At a source-film distance of 1 meter, an exposure of approximately 18 by 20 cm was made. The difference in overall dimensions of the light localizer and the x-ray beam was 0.8 by 0.6 cm, and the maximum error in placement of a single edge was 1.2 cm. The collimator does not have a scale to indicate the beam size numerically.

3.7 INHERENT FILTRATION

The inherent filtration of the tube housing was determined by comparison of absorption curves with a machine of known filtration and voltage.[2] The machine used for comparison had 1 mm of beryllium in the x-ray tube, 1.5 mm beryllium and 0.25 mm aluminum added, giving a total of about 0.3 mm aluminum equivalent filtration. Its power supply filtering was such that the tube voltage peak was 98 kV and fell 4 kV between power supply pulses. This

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[1] INTERNATIONAL COMMISSION ON RADIOLOGICAL UNITS AND MEASUREMENTS. Report 10f 1962, Methods of Evaluating Radiological Equipment and Materials. National Bureau of Standards Handbook 89, p. 1 (1963)

[2] QUIMBY, E.H., L.S. TAYLOR, and O. GLASSER, ET AL. Physical Foundations of Radiology (3rd edition). Paul B. Hoeber, Inc., New York. pp. 258-260 (1961)

variation between 94 and 98 kV is similar in effect to the variation in tube voltage in the Picker machine during a 98-kV, 4-mAs exposure. Absorption curves in aluminum were prepared at these operating conditions with identical geometry for the two machines, except that all distances from the focal spot were doubled with the Picker unit. The kV and mAs used were measured rather than indicated values. The curves extended to 5 mm aluminum for the Picker machine and to 10 mm for the comparison machine. Radiation measurements for the the Picker curve were made with a Victoreen integrating ratemeter, model 555, and a 1DA chamber. Radiation from the comparison machine was measured with a free-air ionization chamber.

One absorption curve was prepared for the Picker unit with only the tube housing window in the beam. This curve from 0 to 5 mm closely matched the comparison curve from 0.5 to 5.5 mm, indicating that the Picker tube head had approximately 0.5 mm more filtration than the comparison machine, or about 0.8 mm. A similar comparison of curves indicated that the Picker tube head and collimator together had filtration of approximately 1.1 mm. A plate on the collimator gives the inherent filtration of the housing as 1.2 mm and the total as 1.35 mm. The machine was furnished with 3.0 mm of added filtration, for a total of 4.1 mm aluminum, which was also found by comparison of absorption curves.

3.8 HALF-VALUE LAYER

Absorption in aluminum was measured and the first and second half-value layers determined from the resulting absorption curves. Radiation measurements were made with a Victoreen integrating ratemeter, model 555, and a model 1DA ion chamber. Energy dependence corrections were less than 5 percent and were not used. The chamber axis was parallel to the x-ray beam, and the center of the chamber was placed 100 cm from the focal spot, except at 40 kV, where it was at 50 cm. The absorbers and a lead sheet with a 1-inch hole were placed halfway between the focal spot and the chamber. The lead sheet, placed next to the chamber side of the absorbers, limited the beam size to slightly larger than the chamber. Half-value layer measurements were not corrected to zero beam size

as suggested by Trout,[3] since the maximum error from this cause is reported to be about 2 percent at 100 kV for the geometry used.

The first and second half-value layers in millimeters of aluminum and the homogeneity coefficients are given in table 2. The homogeneity coefficient is the ratio of the first and second half-value layers and gives an index of the energy distribution of the beam.

Table 2. Half-value layers and homogeneity coefficients.

kV	mAs	First HVL	Second HVL	Homogeneity coefficient
40	2	1.6	1.7	0.94
40	16	1.4	1.5	0.93
40	30	1.3	1.5	0.87
40	Full	1.3	1.5	0.87
70	2	2.8	3.8	0.74
70	16	2.6	3.6	0.72
70	30	2.4	3.2	0.75
70	Full	2.3	3.0	0.77
100	2	4.2	5.7	0.74
100	16	3.9	5.6	0.70
100	30	3.7	5.1	0.72
100	Full	3.2	4.4	0.73

[3] TROUT, E. D., ET AL, Determination of half-value layer. Amer J Roentgen, Radium Therapy and Nuclear Medicine 84:4:729 (1960)

The half-value layer decreases with increasing mAs because the tube voltage falls as the capacitors discharge. (The homogeneity coefficients would be expected to follow a similar trend if the half-value layer measurements were sufficiently accurate to allow reliable calculation of nearly identical homogeneity coefficients. This would require knowledge of half-value layers to within $\pm$ 0.02 mm aluminum.)

3.9 RADIATION OUTPUT

Because the tube voltage falls as the tube conducts and the capacitors discharge, the radiation output per mAs is not constant throughout an exposure. Each mAs causes the tube voltage to fall 1 kV, and the radiation output per mAs depends only on the voltage, not the total mAs of the exposure. For example, a 70-kV, 20-mAs exposure produces about the same exposure as the sum of 70-, 65-, 60-, and 55-kV, 5-mAs exposures, each of which reduces the tube voltage 5 kV. Figure 5 is a graph of radiation output at 1 meter for 5-mAs (measured) exposures as a function of starting voltage.

3.10 TUBE HOUSING LEAKAGE

With the beam port blocked with more than 10 half-value layers of lead as recommended by the NCRP [4], the tube housing was wrapped in x-ray film. After 20 exposures at 100 kV, 10 mAs, the film was processed and examined to discover radiation leaks. The most intense leak was found to be at the junction between the tube housing body and face plate on the front side. Measurements with a Victoreen 666 and the 4-inch chamber indicate, after energy dependence correction of plus 10 percent, that this leak emits 0.03 mR per 100-kV, 10-mAs exposure at 1 meter.

With the filters and collimator in place and the collimator closed, the leakage was again checked. The added filtration was located between the collimator and the tube housing and was not shielded around its edges.

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[4] NATIONAL COUNCIL ON RADIATION PROTECTION AND MEASUREMENTS. Report No. 33, Medical X-ray and Gamma Ray Protection for Energies up to 10 MeV. NCRP, Washington, D.C., p. 15 (1968)

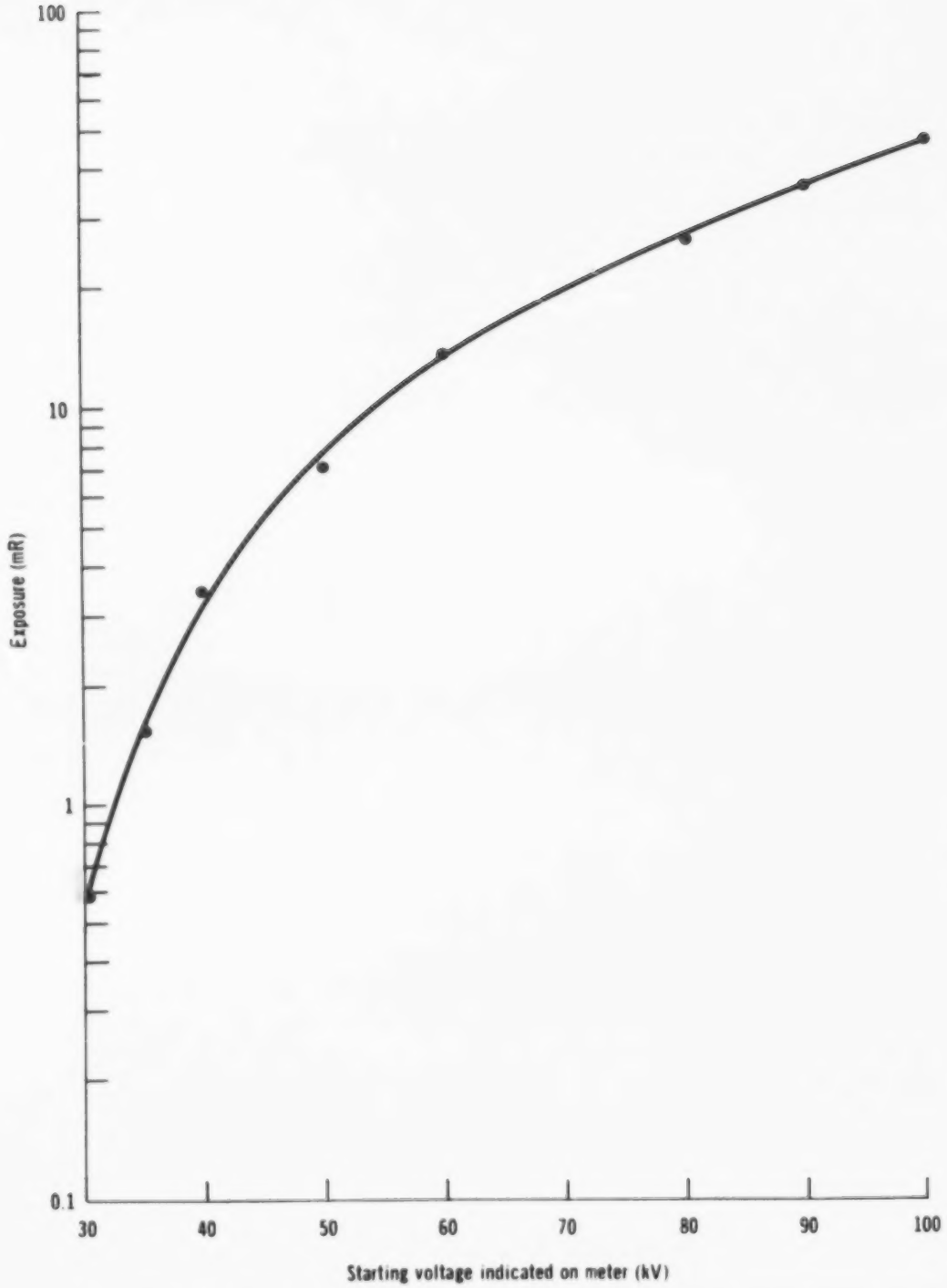

Figure 5. Radiation output at 1 meter for 5-mAs exposures as a function of starting voltage.

The worst case was scatter perpendicular to the beam from the added filtration, which produced an exposure of 0.11 mR per 100-kV, 10-mAs exposure at 1 meter. Although this is not leakage from the tube housing, it is functionally equivalent and the same recommendation applies.[5]

The actual mAs in an indicated 10-mAs exposure at 100 kV was found to be 8.6 mAs, resulting in 1150 heat units per exposure. Since the maximum anode cooling rate is 11,000 heat units per minute, this exposure could be repeated 575 times per hour. Thus, the maximum exposure is 63 mR in 1 hour at 1 meter, which is within the NCRP recommended limit of 100 mR in 1 hour.[6]

3.11 SPURIOUS RADIATION

Because the full voltage is applied to the tube whenever the capacitors are charged, instead of only during exposure as in the case of conventional machines, capacitor discharge machines have the capability of emitting x rays at times other than during an exposure. This machine emits such spurious radiation in three cases. In each case, the radiation originates at the focal spot and passes out the beam port. The three cases are: (1) when the main power switch is turned off, (2) field emission whenever the capacitors are charged above approximately 85 kV, and (3) when the mechanical discharge handle is operated. These conditions are described below. Except where noted, all measurements were made with a Victoreen 666 and the 4-inch chamber. Readings were increased by 10 percent to correct for energy dependence.

(a) Power Switch Operation

If the power switch is turned off while the capacitors are charged, a short pulse of radiation is emitted. This occurs because the filament is partially heated even when the unit is not being operated and the grid bias is removed when the power is turned off. Current can then flow through the tube for a fraction of a second while the filament cools. At 100 kV, the exposure is 0.03 mR at 1 meter, equivalent to 0.003 mAs.

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[5] Ibid., p. 12.

[6] Ibid., p. 15.

However, if the power switch is turned off while the filament is heated to full temperature by the exposure preparation button, the exposure is much greater. At 100 kV, if the switch is turned off while the preparation button is pressed, the exposure is 33 mR at 1 meter, equivalent to about 3 mAs. This is quite likely to cause significant degradation of any radiograph if the machine is turned off before the cassette is moved, and also poses a potential hazard to the operator. The 0.03-mR pulse resulting if the filament is at the standby temperature when the power is turned off is unlikely to degrade a radiograph unless it is closer to the focal spot than is normal for most radiographic techniques. Therefore, the power should not be turned off until a few seconds after the preparation switch has been released. No warning to this effect was included in the instruction manual supplied with this machine.

(b) Field Emission (Dark Current) Radiation

Whenever the capacitors are charged to a sufficient voltage, a small current flows in the tube. This occurs because the electric field strength at the grid is sufficient to cause electrons to be pulled from its surface and strike the anode. This small current is not affected by either grid bias or filament temperature. At 100 kV, this field emission current produces observed exposure rates of 0.1 to 0.7 mR/hr at 1 meter. The rate is variable, depending on tube temperature and past operation. As the tube voltage falls, the intensity falls; it is less than 0.01 mR/hr at 85 kV. The voltage normally falls from 100 to 85 kV in 1-1/2 minutes, and the integrated exposures observed were between 0.001 and 0.005 mR at 1 meter. This is not significant and is unavoidable with the tube type used. The Picker Corporation has indicated that four tubes tested for this type of radiation showed a range of about a factor of two, at about the same magnitude as the machine tested for this report. Because of the extreme variability of exposure, it is not known whether the observed exposures above represent absolute limits.

(c) Discharge Handle

Operation of the discharge handle can produce two types of spurious radiation. The kV meter is in the anode circuit, so for safety, the discharge handle shorts the cathode capacitors first. This causes a short pulse of radiation. Since the grid bias is derived from the cathode voltage, the grid is shorted before the anode voltage is removed, allowing conduction through the tube. If the anode capacitors are not discharged immediately after the cathode capacitors, which can occur if the handle is pulled only part way, conduction will occur and radiation will be emitted until the anode is discharged.

The pulse emitted when the cathode is discharged is normally about 0.03 mR at 1 meter and 100 kV. Occasionally, however, this pulse may be in the 0.5 to 4.0 mR range. These large pulses are accompanied by a brilliant flash of light from the region of the cathode. This pulse occurs whether the filament is heated or not. To study it more thoroughly, a stop was placed on the handle between the cathode and anode discharge positions so that the anode could not be discharged. This permitted a relatively repeatable method of pulling the handle. It was found that a large pulse was much more likely to occur (about 1 in 10) if the cathode discharge point was approached very slowly. A fluorescent screen and silicon solar cell indicated that the small pulses are less than 20 μsec in duration while the larger ones are 0.5 to 1.5 msec long, with roughly constant amplitude throughout. Because of the short duration of these pulses, readings were corrected for chamber saturation using information in the Victoreen 666 instruction manual. Placing 8 mm aluminum in the beam at 100 kV attenuated the pulse by a factor of 10, indicating that the radiation is caused by an accelerating potential of 50 kV. This means that although the electrons were apparently emitted from the cathode while its voltage was falling to zero, most of their flight occurred after it had reached zero. A 50-kV, 4-mAs exposure produces 6 mR at 1 meter. Therefore, a typical pulse of 1.5 mR is equivalent to 1 mAs. Its duration of 1 ms indicates a tube current of about 1000 mA. If the anode is not rotating when this occurs, the result is a melted spot. This occurred numerous times in this testing. Conduction of 1 mAs through the tube should cause the anode voltage to drop 0.5 kV. However, it was observed to drop a variable amount, up to 35 kV, when a large pulse occurred.

This drop in anode voltage occurred only when a large pulse was emitted, but the amount of the drop did not seem to be related to the magnitude of the pulse.

In addition to the pulse that occurs when the cathode is discharged, the loss of grid bias permits conduction until the anode is discharged if the filament is heated to its standby temperature. If the capacitors are initially charged to 100 kV and the cathode side discharged, the exposure rate is 110 mR/hr at 1 meter. Inserting 8 mm aluminum in the beam reduced the exposure rate to 10 mR/hr, confirming that this is 50 kVcp radiation. If the anode capacitors are allowed to discharge through their bleeder resistor, the total exposure is 4.0 mR at 1 meter. This radiation occurs because electrons are emitted from the filament even when it is at the standby temperature and increases greatly if it is brought to operating temperature while the anode is charged and the cathode is not.

The case described in paragraph (a) and the second case described in (c) above can be eliminated by increasing the value of the filament standby-current-limiting resistors from 150 to 250 ohms. This reduces the filament temperature so that electron emission and the resulting radiation is reduced by a factor of about 100. The field emission radiation described in paragraph (b) and the first case described in (c) are not affected by this change because the tube current in these cases does not depend on emission due to heating of the filament.

In addition to these observed cases of spurious radiation, failure of the x-ray tube grid bias would result in radiation being emitted other than during an exposure. If the filament standby temperature is too high, current would flow in the tube whenever the capacitors are charged if the grid bias fails. The radiation level depends on the filament temperature, and was found to be 100 mR/hr at 1 meter and 50 kV for this machine. If the filament standby temperature is reduced as described above, this type of radiation is reduced. When the filament is heated to full temperature without grid bias, conduction occurs without pressing the exposure switch. Radiation is emitted prematurely at the same rate as during a normal exposure.

With no grid bias, the exposure cannot be terminated at the proper mAs value, and a full discharge exposure occurs unless the exposure preparation switch is released quickly. Although grid bias failure did not occur during these tests, the bias voltage appears between two conductors of the cathode high-voltage cable and a breakdown is possible. This condition cannot be detected until an exposure is attempted and the operator notices that the kV meter begins falling or the exposure light comes on before the exposure switch is pressed.

3.12 BEAM QUALITY COMPARISONS WITH FULL-WAVE MACHINES

In a capacitor discharge machine, the tube voltage is at its peak voltage at the beginning of an exposure and falls to a level determined by the mAs of the exposure, possibly only a few kV below the peak. In a full-wave radiographic machine, the tube voltage fluctuates between its peak value and a minimum value often much less than the peak 120 times a second. The tube voltage on the low mAs capacitor discharge exposure only falls a few kV below the starting voltage, while it falls to zero in the full-discharge case, resulting in a much lower average voltage. For a low-mAs exposure on a capacitor discharge machine, the beam will contain a greater percentage of photons near the peak energy than a full-discharge exposure. A full-wave machine with its pulsating tube voltage will be intermediate in beam hardness between these two cases. Although its voltage varies from zero to the peak value, the tube current is higher near voltage peaks, causing the beam to be harder than the full-discharge case. Various comparisons which were made between the two types of equipment are described in the following paragraphs.

3.12.1 Half-Value Layers

In the same manner as with the Picker machine, an absorption curve was determined for a Machlett Dynamax HD-50D x-ray tube. This tube is specified by the manufacturer as having 0.7 mm aluminum inherent filtration, so 3.4 mm aluminum was added to make this tube comparable to the Picker. The tube was operated at a measured voltage of 69 kVp full-wave rectified at 50 mA. The half-value layers are shown in table 3 along with the corresponding measurements in the Picker machine at 70-kV preset starting voltage which was measured to be 69 kV.

Table 3. Comparison of half-value layers, measured technique factors.

	Picker				Dynamax HD-50D
	69 kV, 3.7 mAs	69 kV, 15.6 mAs	69 kV, 34.4 mAs	69 kV, Full	69 kVp, 50 mA
1st HVL	2.8	2.6	2.4	2.3	2.7
2nd HVL	3.8	3.6	3.2	3.0	3.5

Table 3 shows that at 69 kVp the full-wave rectified machine produces a beam intermediate in hardness compared to low-mAs and full-discharge exposures on the Picker machine.

A gamma ray spectrometer was used to determine spectra of the same beams for which half-value layers are listed in table 3. Differences in the observed spectra were small and suggested the same differences that were more clearly demonstrated by half-value layers.

3.2.2 Step-Wedge Radiographs

To provide quantitative information on radiographic comparison, radiographs were taken of an aluminum penetrometer with step thickness of 5 to 35 mm. The Picker machine was compared with the Dynamax HD-50D tube with full-wave rectification and 4.2 mm aluminum total filtration. Kodak Blue Brand film and par-speed screens were used. After the correct technique factors were determined, the two step-wedge images to be compared were taken side by side on the same film to eliminate processing differences. Technique factors were chosen to match gross densities at about 0.50 and 2.60 density units, corresponding to 26 mm and 8 mm on the two images. These densities span most of the useful range in diagnostic radiography. The technique factors measured were 77 kV, 7-1/2 mAs for the Dynamax and 71 kV, 3.7 mAs for the Picker. Table 4 lists the densities of each step. The maximum difference is 0.05 density unit, and the two images are almost indistinguishable.

Table 4. Step-wedge densities.

mm Al	Picker 71 kV, 3.7 mAs (Total density)[a]	Dynamax HD-50D 77 kV. 7.5 mAs (Total density)[a]
5	3.02	2.97
8	2.61	2.60
11	2.14	2.13
14	1.61	1.64
17	1.20	1.23
20	0.92	0.94
23	0.68	0.70
26	0.50	0.53
29	0.42	0.44
32	0.38	0.39
35	0.37	0.37

[a] Base fog = 0.33

3.12.3 Phantom Radiographs

Radiographs of a hand phantom and a hip phantom were taken with the Picker machine and the Dynamax unit. Two sets of comparable radiographs were obtained for the hip phantom. One was with measured technique factors of 77 kV, 7-1/2 mAs on the Dynamax and 71 kV, 3mAs effective (achieved by increasing distance with a 3.7 mAs actual exposure) on the Picker; the other was with 69 kV, 15 mAs on the Dynamax and 63 kV, 13 mAs on the Picker. Comparable radiographs were obtained for the hand phantom with 65 kV, 2-1/2 mAs on the Dynamax and 60 kV, 2.4 mAs effective on the Picker. In each case Kodak Blue Brand film was used with par-speed screens, and each pair of comparable radiographs was nearly identical in density and contrast.

4. CONCLUSIONS AND RECOMMENDATIONS

As a result of this evaluation, certain suggestions for improving the radiation safety of this machine were made by the Division of Electronic Products to the Picker Corporation. Because the full position on the mAs control is not radiographically useful but could be used in an attempt to increase density, the Division of Electronic Products has recommended that it be removed, and Picker has agreed to eliminate it from future units. They have also agreed to change the filament standby-temperature-limiting resistors to 250 ohms, as described in the spurious radiation section. This will be done on units already in service as well as on future units.

In addition to these changes in the circuitry of the machine, additions will be made to the information furnished with it. Warning tags indicating that the unit may be hazardous unless used by trained personnel and that it should not be used in explosive atmospheres will be attached to all units, including those already in service. The instruction manual will be revised to include sections describing the effects of loss of grid bias, a procedure for shutting down the unit to minimize spurious radiation, and proper use of the discharge handle.

APPENDIX A

SPECIFICATIONS

Manufacturer:	Hitachi Roentgen Co., Tokyo, Japan
U.S. Distributor:	The Picker Corporation
Power Requirement:	100, 110, 115, 200, 220 or 240 V, 0.5 kVA continuous, 2.5 kVA intermittant
Maximum Tube Voltage:	100 kV
Charge Storage Capacitance:	1.0 μF
X-ray Tube:	2 x 2 mm focal spot, rotating anode, grid controlled
Overall Height:	6' 4"
Width:	2' 2"
Height of Focal Spot:	8" to 7' 3" above floor
Weight:	617 lbs

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15. Supplementary Notes

16. Abstracts

Tests were performed on a Picker model DGC-1010 capacitor discharge mobile x-ray machine to determine accuracy of voltage and current-time indications, line voltage effects and current drain, exposure reproducibility, focal spot size and location, correspondence between the collimator and light localizer, inherent filtration, half-value layer, radiation output, and tube housing and collimator leakage. Spurious radiation was found to originate in the tube under certain conditions. These conditions were investigated, and the observed radiation levels are reported. To determine beam quality differences between capacitor discharge and conventional equipment, comparisons were made of half-value layer and step-wedge and phantom radiographs

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KEYWORDS: Capacitor Discharge X-ray Machines; Mobile X-ray Machines; X-ray Equipment; X-ray Machine Evaluation.

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